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Artificial Heads for High-Level Impulse Sound Measurement

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If the Insertion Loss (IL) of hearing protectors has to be determined with very high impulse or continuous noise levels, the acoustic insulation of the Artificial Test Fixture has to exceed at least the Insertion Loss (IL) of the hearing protector. An another requirement when evaluating ear muffs, is an adequate reproduction of the pinna and the circumaural area. For the evaluation of ear plugs and hearing protectors using Active Noise Cancellation (ANR) the impedance of the eardrum must be properly reproduced. These requirements have not been always fulfilled by commercially available artificial heads. Therefore, a special device for this type of measurement has been designed and built in our laboratories.

The head has been molded with Polyurethane material in a way, that the HEAD Acoustics external ear and circumaural area could be fit. In order to simulate the acoustic impedance of the human ear, a Bruel & Kjaer ear simulator has been used.

The acoustic insulation of the ATF is better than the requirements of the different standards. The Transfer Function of the Open Ear (TFOE) is very close to the data published by Shaw. The device is linear up to peak pressure levels of 190 dB.

It is possible with this ATF, to evaluate the IL of all types of hearing protectors up to pressure levels of 190 dB.

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ARTIFICIAL HEADS FOR HIGH-LEVEL IMPULSE SOUND MEASUREMENT

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ABSTRACT

If the Insertion Loss (IL) of hearing protectors has to be determined with very high impulse or continuous noise levels, the acoustic insulation of the Artificial Test Fixture has to exceed at least the Insertion Loss (IL) of the hearing protector. An other requirement when evaluating ear muffs, is a adequate reproduction of the pinna and the circumaural area. For the evaluation of ear plugs and hearing protectors using Active Noise Cancellation (ANR) the impedance of the eardrum must be properly reproduced. These requirements have not been always fulfilled by commercially available artificial heads. Therefore, a special device for this type of measurement has been designed and built in our laboratories.

The head has been molded with Polyurethane material in a way, that the HEAD Acoustics® external ear and circumaural area could be fit. In order to simulate the acoustic impedance of the human ear, a Brüel & Kjaer ear simulator has been used.

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It is possible with this ATF, to evaluate the IL of all types of hearing protectors up to pressure levels of 190 dB.

INTRODUCTION

The Insertion Loss (IL) of hearing protectors is usually determined with the standardized Real Ear At Threshold (REAT) [1] method. Some protection devices, like non linear earplugs and ear muffs or active hearing protectors cannot be characterized at such low levels. These devices have to be evaluated at the sound pressure levels at which they are supposed to work. Especially, hearing protectors that will be used in

extreme high levels (e.g. soldiers near weapons may be exposed to peak levels as high as 190 dB) should always be tested at these levels, because even so-called linear hearing protectors may become nonlinear [2]. As, for very high levels, it is not possible to use any evaluation method where human subjects are involved, the use of some type of Artificial Test Fixture (ATF) or artificial head is implicit.

REQUIREMENTS FOR THE ATF

If this type of testing device is to be used for all types of hearing protectors (e.g. ear plugs, ear muffs, level dependent devices, ANR equipped devices ...) in different noise environments (shock waves from different angles, impulse and continuous noises in reverberant rooms ...) the following points should be taken into account:

- the acoustic insulation of the measurement system, with hermetically sealed ear canal, has to be better than the insertion loss of the tested hearing protector.
- the average human ear canal has to be reproduced as good as possible, to make sure that earplugs can be tested close to real conditions.
- the pinna and the outer ear are to be reproduced in a way to show a comparable

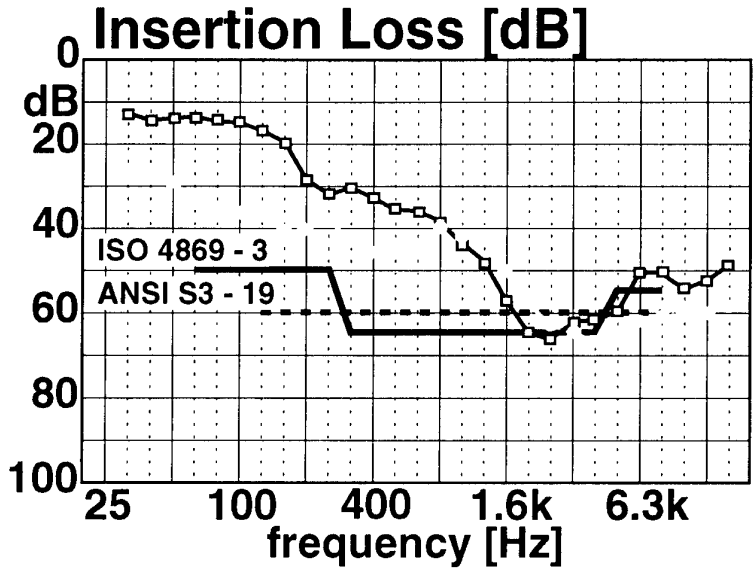

Fig. 1:
Acoustic insulation of two different commercially available artificial Heads compared to the ISO and ANSI requirements.

diffraction as the human head.

- the mechanical impedance of the circumaural area should be comparable to that of the human skin in this area, in order to show the same interaction with the cushions of the ear muffs.
- the acoustic impedance at the drum (microphone) must be comparable to the impedance seen in the human ear, because it may influence the measured IL, especially when measuring ear plugs or ANR protection devices.
- the microphone must be able to handle high pressures at the eardrum. Due to the transfer function of the outer ear (diffraction of the head, transfer function of the pinna,

transfer function of the ear canal this pressure may be up to 20 dB higher than the pressure in the free field).

COMMERCIALLY AVAILABLE ARTIFICIAL HEADS

Artificial heads that are commercially available are usually designed for the evaluation of communication devices. In this case the main concerns are the good restitution of the acoustic signal at the eardrum. Therefore, the diffraction of the head, the different impedance of the outer ear (pinna, ear canal, eardrum) are usually well reproduced.

The main problem of the evaluated commercially available artificial heads was the lack of acoustic insulation. Figure 1 shows the measured ILs, and compares them to ISO [3] and ANSI [4] requirements. Neither fulfills the criteria of these standards. They are therefore not suitable for IL measurements, especially in high level impulse noise.

ISL ARTIFICIAL HEAD

As the use of commercial products was not compatible with the requirements for the evaluation of hearing protectors with high level impulse noise, we designed and built an ATF especially for this purpose.

The main problem in the development of this ATF was to find a way of introducing better insulation. In order to do this, the first step consisted in encapsulating the microphone and its preamplifier together with the ear simulator. Figure 2 shows the different parts of the system (left) and the assembled system (right). However this has

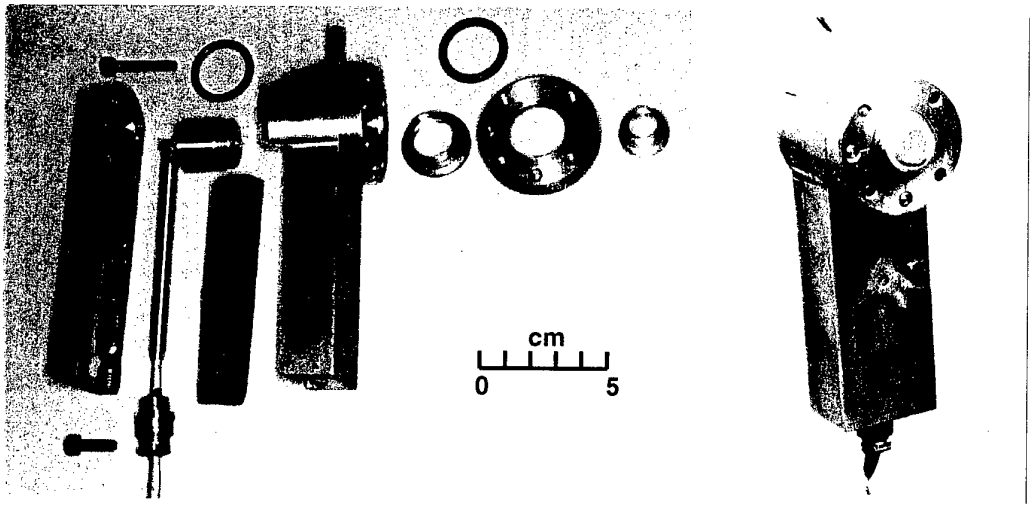

Fig. 2: The encapsulated measurement system and its different parts

not been enough to obtain enough insulation. So, in a second step, the measurement element has been mechanically uncoupled from the shell of the artificial head as it is shown in figure 3. With the help of this special mounting of the measurement element, it has been possible to improve the IL of the artificial head to a value exceeding 60 dB for all frequencies as it is shown in figure 4 [5].

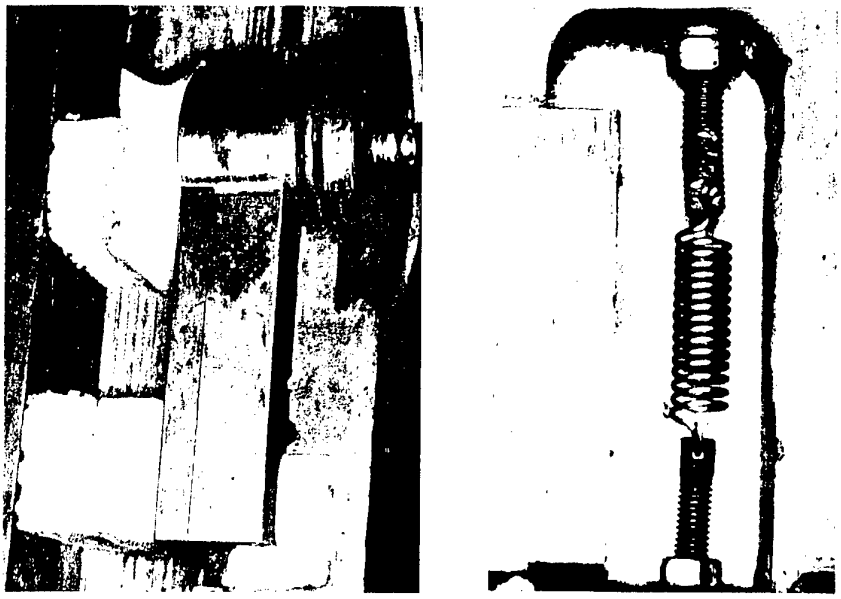

Fig. 3: Placement of the measurement element inside the artificial head (left) and its fixation with a spring (right)

In order to have a good representation of the ear canal, the pinna and the circumaural region, we used the outer ear made by HEAD Acoustics. It includes an ear canal, the pinna and the circumaural region. The major advantage of its design is, that the mechanical impedance of the flesh simulation in the ear canal and the circumaural region is close to human values. This is important, especially for the evaluation of ear plugs.

Fig. 5: the ISL artificial head

The model for the head mold (figure 5) was BAMAR (Bioacoustic's Anthropometric Manikins for Acoustic Research)..

One way to evaluate the quality of the reproduction of the head and the external ear, is to measure the Transfer Function of the Open EAR (TFOE). This function has been measured by SHAW [6] for human. In figure 6 the TFOE of human is compared to the TFOE measured with the artificial head. It is shown for two different angles of sound incidence (0° and 90°). For either incidence,

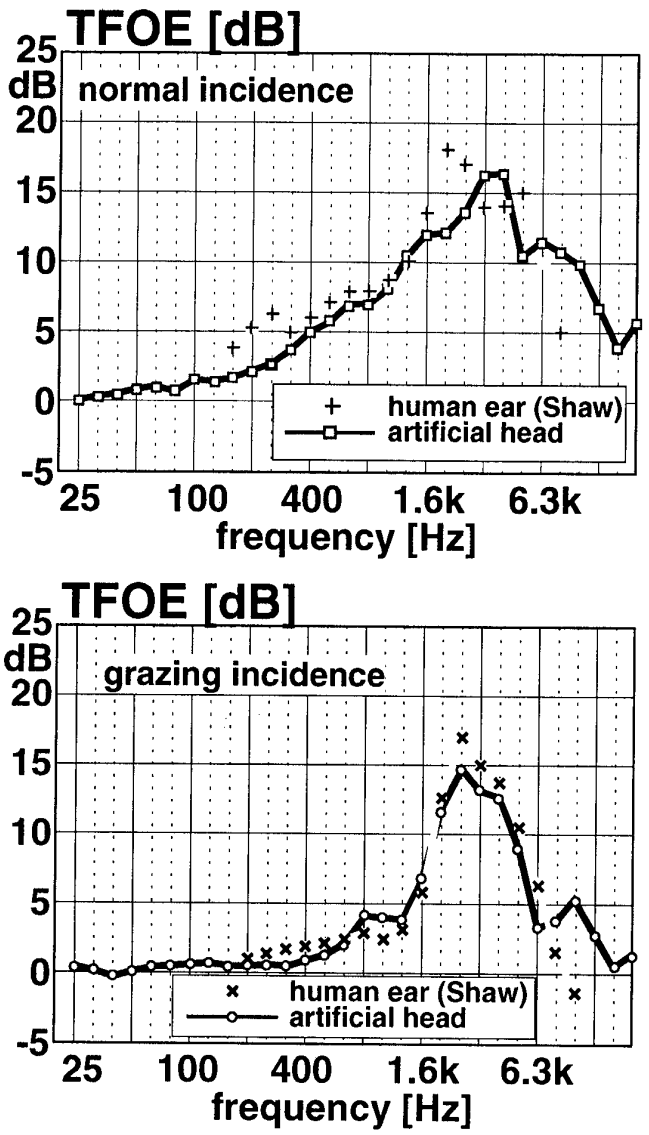

Fig. 6:
Transfer Function of the Open Ear for normal (upper) and grazing incidence (lower).
The experimental data (ISL artificial head) are compared to human data published by Shaw [6].

the curves are very close. This shows, that the diffraction of the head and the pinna, as well as the transfer function of the ear canal and the drum are comparable to human.

CONCLUSION

It is possible to determine the physical performance of all kinds of hearing protectors with an artificial head, but only if it is designed for this purpose. This means, that the acoustic insulation has to be higher than the possible IL of the tested hearing protector. Furthermore, in order to be able to reproduce results obtained with the REAT method, all acoustic and mechanical impedances involved in the measurement (eardrum, ear canal, pinna ...) should be as close as possible to human values.

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